



An Automated Classification Technique for Detecting Defects in Battery Cells

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Abstract

Battery cell defect classification is primarily done manually by a human conducting a visual inspection to determine if the battery cell is acceptable for a particular use or device. Human visual inspection is a time consuming task when compared to an inspection process conducted by a machine vision system. Human inspection is also subject to human error and fatigue over time. We present a machine vision technique that can be used to automatically identify defective sections of battery cells via a morphological feature-based classifier using an adaptive two-dimensional fast Fourier transformation technique. The initial area of interest is automatically classified as either an anode or cathode cell view as well as classified as an acceptable or a defective battery cell. Each battery cell is labeled and cataloged for comparison and analysis. The result is the implementation of an automated machine vision technique that provides a highly repeatable and reproducible method of identifying and quantifying defects in battery cells.

Introduction

The problem of identifying battery cell defects is a tedious and time-consuming process that is primarily done manually by a human inspection process. Each individual battery cell is visually inspected for known defects or historical patterns that lead to future defects such as battery leakage and salt creep across batteries. By detecting battery defects early enough, one can avoid having to reject entire batches of cells by localizing potential problems in the production of battery cells. This requires the need for frequent inspection of all battery cells over a predetermined time period where all battery cells need to be inspected more than once in order to minimize defects in the final production process. Since the current “expert” in determining and classifying defects is a human operator, it is important to study and observe a number of human operators to be able to automatically predict what defects occur over time and how to accurately classify these defects. In order to successfully implement our automated technique, we observed and recorded human operators over the course of several days and used this information to develop an automated classification technique for detecting battery cell effects.

Based on our observations and surface science analysis of human inspection results, it is now possible to automatically detect battery cell defects using our machine vision and image processing technique. We have developed a morphological feature-based imaging technique that will automatically determine if a battery cell is acceptable for use. Our technique uses a three-step process in order to determine if a battery cell is acceptable or defective. First we determine the battery cell view by using a two-dimensional fast Fourier transform (FFT) technique, which yields distinctly different results for a cell with and without tape. Next we locate and delineate the battery cell, which involves utilizing several traditional machine vision techniques. Finally, we determine cell quality based on analyzing over 500 individual battery cell images in order to accurately identify “good or acceptable” and “bad or unacceptable” battery cells based on expert human identification techniques. The result of this analysis is a machine vision technique for identifying and classifying each battery cell as acceptable or defective. By implementing our technique,

one can save valuable time and resources as well as increase efficiency. What follows is a description of our automated battery cell detection technique.

Materials and Methods

The goal of this technical memorandum is to present a novel technique for automatically detecting and classifying defects in battery cells utilizing a morphological feature-based classifier. We utilized our compact microscope imaging system for the successful implementation of this technique. Our Compact Microscope Imaging System with Intelligent Controls (CMIS) is a miniature diagnostic microscope analysis system combining intelligent machine vision and image processing with remote control capabilities. The CMIS can be used in-situ with a minimum amount of user intervention. It incorporates the ability to auto-focus on a sample via a microscope or camera system, automatically scan an image and perform machine vision analysis on multiple samples simultaneously. The system can run, control, and analyze experiments automatically and remotely.

Using our CMIS system, a battery cell image is first captured by the microscope camera system and image processing board. Next we determine if the battery cells is acceptable or defective using the following steps:

Step 1 Determine Battery View

Two types of configurations for the battery cells were analyzed. Some battery cell images were viewed through translucent tape on which the batteries were mounted while others were images of freely standing cells or cells mounted on a clear tape offering an uninhibited view of the battery cell surface. In order to identify the correct configuration, we represented the battery cell image as the magnitude of a two-dimensional fast Fourier transform (FFT) where low frequencies are located in the center of the image and high frequencies are located towards the edges.

Based on our analysis of cell configurations, translucent tape images had a low contrast displaying a small, compact two-dimensional FFT. Images without tape or with clear tape had significant contrast that resulted in a widely scattered two-dimensional FFT. The two-dimensional FFT gives us an efficient and reliable way to determine if a battery cell image consists of tape or not, which is important to determine since each configuration requires a different image analysis technique.

Step 2 Locate and Delimit the Cell

This step encompasses several sub-steps involved in traditional machine vision technology. First, any noise present in the image must be reduced or eliminated. Next, the objects of interest must be located and separated from the background. Once delimited, the objects can be classified. We use one of two similar iterative approaches dependent on whether the image contains translucent tape or not.

No tape or transparent tape: Iterative algorithm

- Low pass filter to remove noise
- Threshold entire image to separate cell from background
- Find all the objects in the image
- Classify the objects—Particles too small are dismissed as noise. Particles large enough are classified as anode or cathode based on diameter. If a cathode or anode is found it is analyzed, and based on the height/width ratio and perimeter length the threshold value is increased or decreased and the procedure continues.

Translucent tape: Iterative algorithm

- Low pass filter to remove noise
- Adaptive threshold based on local neighborhood (size 210 by 210 pixels)
- Find all the objects in the image
- Classify the objects—Particles too small are dismissed as noise. Particles must be cathode (no anode view taken through tape). If a cathode is found, determine if the diameter and height/width ratio are within given tolerances. If not, adjust the threshold algorithm and continue.

The adaptive threshold procedure divides the image into local neighborhoods. For each neighborhood, the average and standard deviation are found. Areas of low standard deviation are all background or all cell. Areas of high deviation are border regions. A local threshold is determined based on the neighborhood histogram.

Step 3 Determine Cell Quality

Anode: Find the gasket and center portion of the cell (disregard transitional bands). Perform a morphological gradient operation on the image to find feature edges. Apply a center-deleted spike filter (clean) to remove one pixel variations and small features. Sum the pixels in the gasket region. Sum the pixels in the center region. Each region is considered separately and has its own critical value that cannot be exceeded to qualify as an acceptable by the user.

Cathode

The pixel intensities within the cell are summed. If the sum exceeds a critical value defined as the maximum acceptable sum, the cell is classified as defective. The maximum acceptable sum can be adjusted to fine tune the classification system. The default value has been experimentally determined based on the typical samples received.

Results and Discussion

Based on implementing steps 1 through 3, we can now determine if a battery cell is acceptable or defective. Based on our analysis of over 500 individual battery cell images, we identified over 20 distinctly different defect categories that were unanimously agreed upon as defects by the human operators who represent the experts or 100 percent accuracy for our technique. What follows are three representative examples of our technique analyzing actual battery cell images.

Example 1 Master Training/Morphological Feature Set 1

An unaltered cell image of an acceptable top or anode view is shown in figure 1. Figure 2 shows the FFT result of figure 1 displaying the color-coded FFT of the cell image and identifying the image as a non-tape view. Although more compact than the bottom view FFT, this FFT is still spread widely enough to indicate a non-tape image. In figure 3, an adaptable contrast threshold value has been determined and the objects in the image have been found, outlined, and labeled. The technique has identified the cell and determined that it is an anode view. In figure 4, a morphological gradient has been performed on the image and the gasket and center regions of the cell have been identified and drawn to the screen for reference. The resulting intensity values are separately summed in the gasket and center regions and compared to the user-defined default values. Both sums are within the user-defined tolerance for an acceptable cell, thus the battery cell is labeled and classified as acceptable.

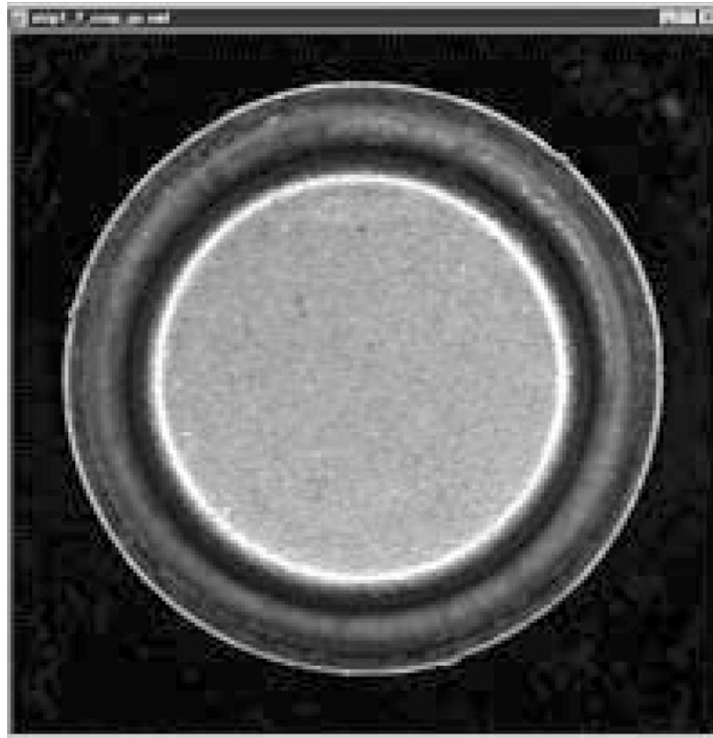


Figure 1.—“Ideal” anode battery cell.

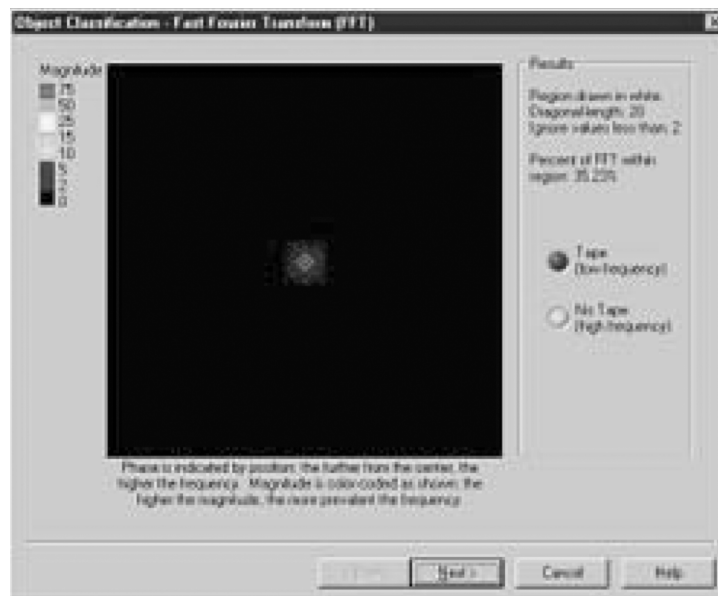


Figure 2.—FFT representation of cell.



Figure 3.—Automatic anode cell identification.



Figure 4.—Ideal anode cell identification showing adaptive range.

Example 2 Master Training/Morphological Feature Set 2

The unaltered cell image of an acceptable bottom or cathode view is shown in figure 5. Figure 6 shows the FFT result of figure 5 displaying the color-coded FFT of the cell image and identifying the image as a non-tape view. Notice the FFT is widely spread, indicating a crisp, high-contrast image consistent with a non-tape image. In figure 7, a threshold value has been determined and the objects in the image have been found, outlined, and labeled. The technique has identified the cell and determined that it is a cathode view. In figure 8, the sum of the pixel intensities has been computed and as it falls well within the default maximum of an acceptable cathode battery cell, battery cell is labeled and classified as acceptable.

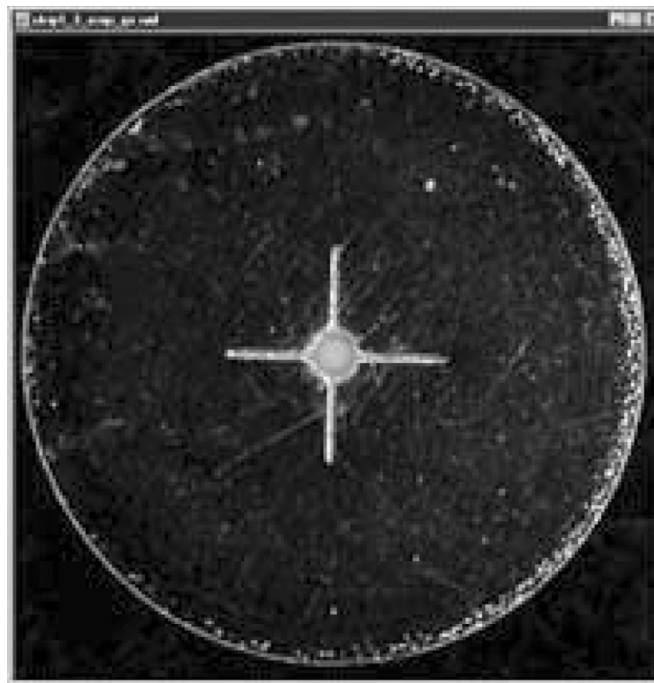


Figure 5.—“Ideal” cathode battery cell.

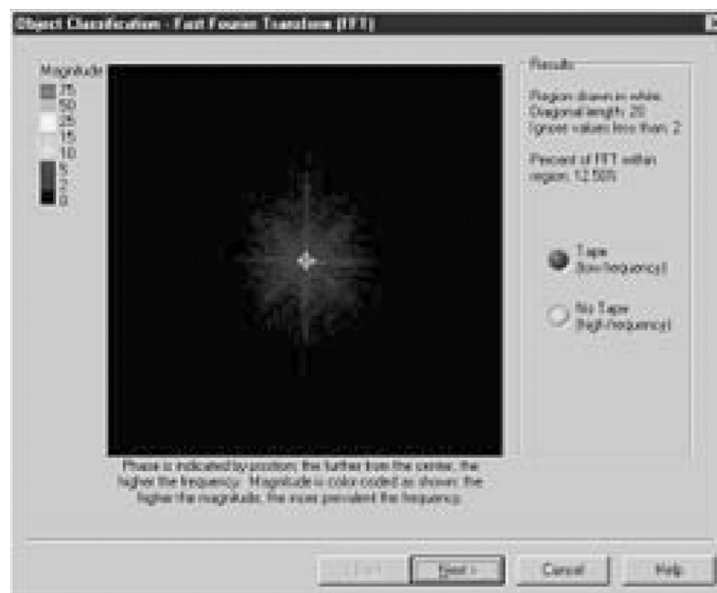


Figure 6.—FFT representation of cell.

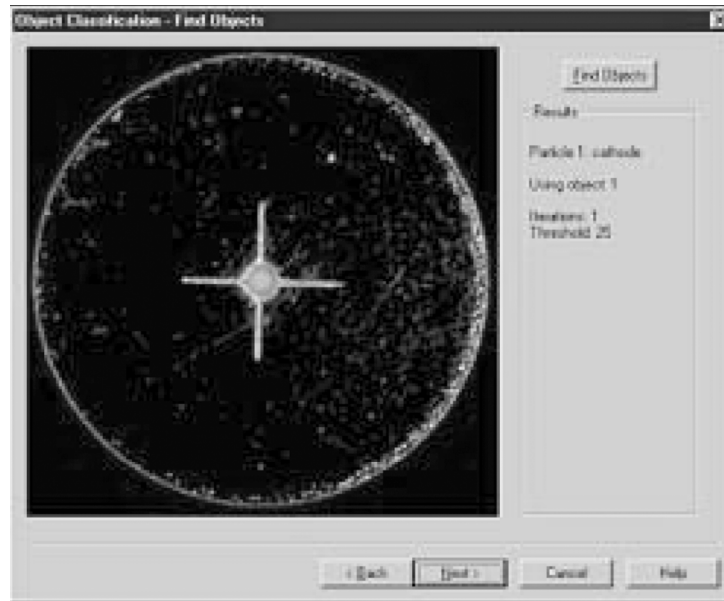


Figure 7.—Automatic cathode cell identification.

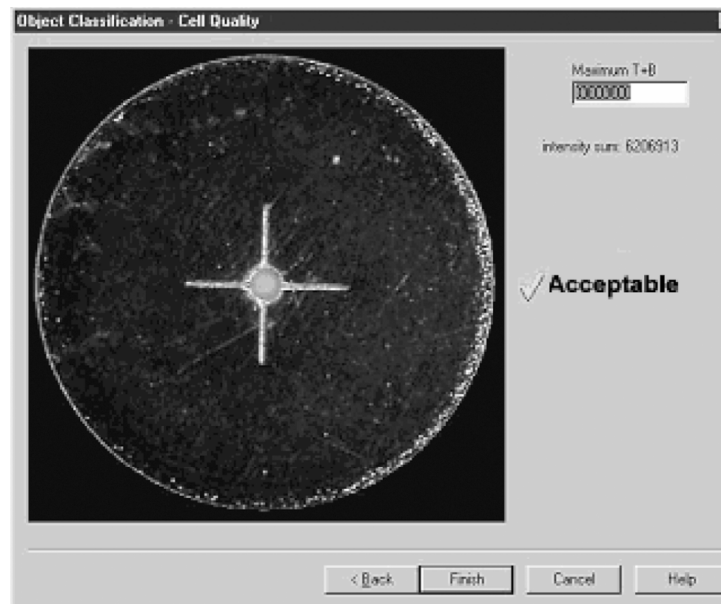


Figure 8.—Ideal cathode cell identification showing adaptive range.

Example 3 Defective Tape/Cathode View

The unaltered cell image of a defective cathode view with tape is shown in figure 9. This cell was initially manually classified as marginally defective due to bubbles. Figure 10 shows the FFT result of figure 9 displaying the color-coded FFT of the image and identifying the image as a tape view. Notice the FFT is very compact, indicating a dull, low-contrast image consistent with a tape image. In figure 11, an adaptive threshold algorithm has determined a series of local threshold values to optimize the separation of the cell from the background. The objects in the image have been found, outlined, and labeled. The technique has identified the cell and determined that it is a cathode view. In figure 12, the sum of the pixel intensities has been computed and as it falls well above the default maximum for an acceptable battery cell, thus the cell is labeled and classified as defective.

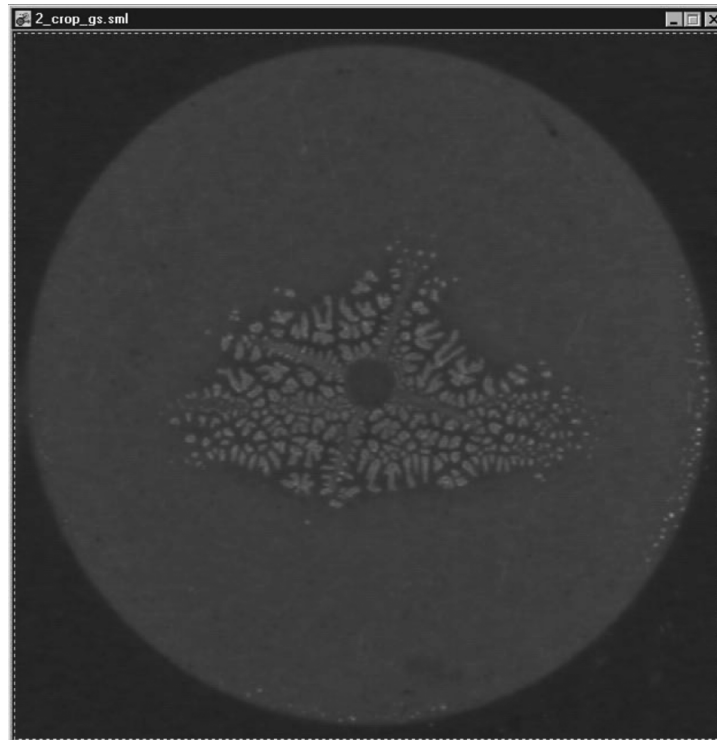


Figure 9.—Defective anode battery cell.

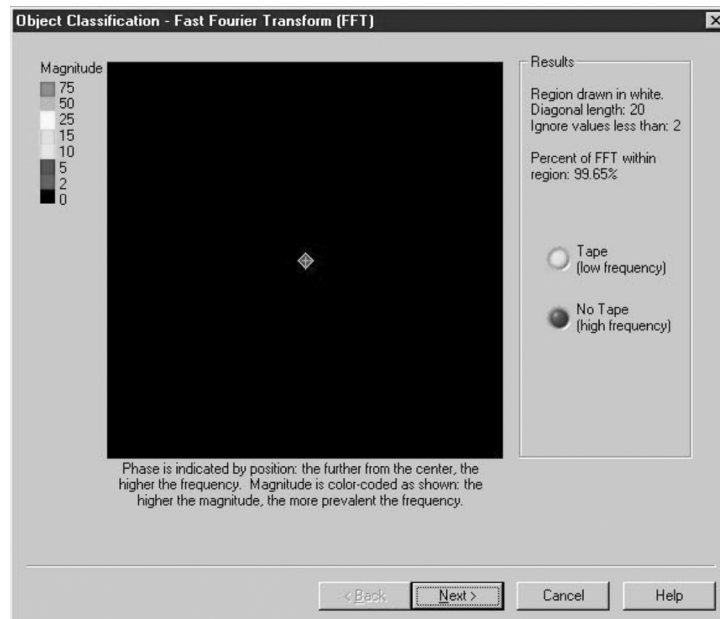


Figure 10.—FFT representation of cell.

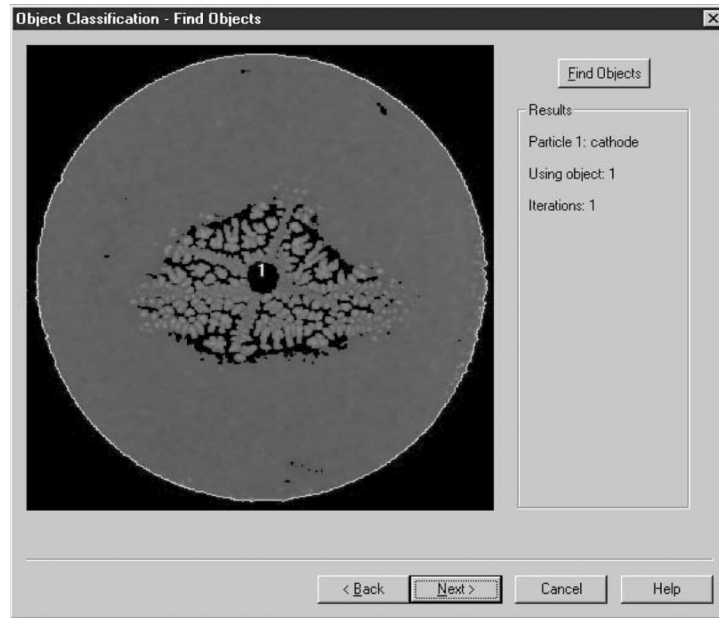


Figure 11.—Automatic cathode cell identification.

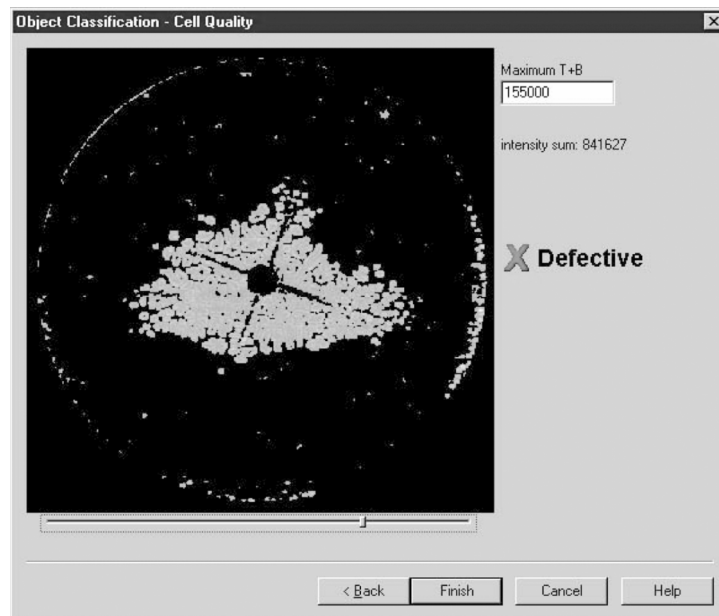


Figure 12.—Cell automatically identified as defective/bad.

Conclusion

A machine vision approach for automatically classifying a battery cell as acceptable or defective has been presented and discussed. This technique utilizes the expertise of human technicians trained to detect defects in battery cells and incorporates this expertise into a machine vision technique that can be easily integrated into an existing image analysis system. This automated battery cell defect classification technique has shown to be capable of accurately and reliably identifying defects in battery cell based on analyzing hundreds of individual battery cell images as well as human expert verification. This technique is readily adaptable to any in-line process inspection problem that involves surface science analysis such as battery cell defects.

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